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OBSERVING THE ICY JOVIAN SATELLITES WITH THE GALILEO PHOTOPOLARIMETER RADIOMETER INSTRUMENT

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ABSTRACT:

The Photopolarimeter/Radiometer (PPR) instrument aboard the Galileo Spacecraft will go into orbit around Jupiter in December, 1995. The 23 month tour offers PPR four Ganymede encounters, three Callisto encounters, and three Europa encounters at less than 3,100 km distance. In addition, there will be one Ganymede, one Callisto, and two Europa 'non-targeted' encounters less than 80,000 km distance. The PPR will have excellent opportunities to do thermal IR, photometry, and polarimetry studies of each of these satellites. The targeted satellite encounters will yield resolutions of down to 0.7 km whereas the non-targeted encounters will give resolutions down to 58 km.

1. INTRODUCTION

The Galileo spacecraft will arrive at Jupiter on December 7, 1995 to commence its nearly two year tour of the Jovian system (Byrnes and Johannesen, 1994). In addition to studying the magnetosphere and Jupiter's atmosphere, the spacecraft will study the Galilean satellites in much greater detail [than that provided by the Voyager flyby encounters]. The Photopolarimeter Radiometer (PPR) instrument is one of the four scan platform remote sensing instruments aboard the Galileo spacecraft. The PPR has been designed to perform precision photometry, polarimetry, and long wavelength (1.7 - 110 μm) radiometry. The PPR instrument was designed primarily to study the Jovian atmosphere and those objectives are described by Russell, et. al., (1992). The icy satellite objectives and observation designs have been fleshed out more recently and are presented here.

Although the expected data return from Galileo is now smaller than what was originally envisioned due to the incomplete deployment of the high gain antenna, the PPR instrument will still return data sets of nearly global coverage of the icy satellites. This is being accomplished partly by the addition of new processing algorithms which will be discussed below. The data return will be further reduced by a strategy that favors global coverage at good resolution, but with fewer wavelengths used for each type of observation. The PPR will also return less data from Collaborative observations with other instruments, called "ride-along" observations. The choice to play back some of these data can be made once telemetry capability

is known. This paper discusses the resulting observing plans of the PPR with the intent of giving the scientific community the background from which to suggest inclusion of important objectives.

This paper will first give an overview of the PPR instrument characteristics followed by the operational aspects to be used during the Jupiter tour, including enhancements designed for the low-rate telemetry environment. The satellite observational plan will be given next, followed by the observation detail.

2. OVERVIEW OF THE PHOTOPOLARIMETER RADIOMETER (PPR) INSTRUMENT

Since a complete description of the PPR instrument has been given by Russell, et. al. (1992), only a brief overview will be given here. The PPR resides in a position on the scan platform of the Galileo spacecraft that allows the PPR to view the largest phase angles. The upper phase angle limit for the PPR is approximately 155 degrees. This limit, imposed by the spacecraft sunshade, depends on the sun-earth separation; the spacecraft is normally earth-pointed. All other scan platform instruments are obscured by the sunshade at lower phase angles. This placement enhances the PPR's ability to observe the night side of the target body which is one of the major objectives. The field of view (FOV) of the PPR is circular with a 2.5 mrad diameter.

The PPR is a hybrid instrument designed to accomplish both precision photometry and radiometry. Table 1 shows the

wavelength coverage afforded by the 23 filter positions on the rotating filter wheel (Russell, et al, 1992). As shown, the instrument has three distinct sections: radiometry, polarimetry, anti photometry.

The radiometry mode utilizes the PPR's two telescopes: the scene view and the space view. A chopper, operating at 30 Hz, alternately directs the flux from the scene and space view telescopes onto the lithium tantalate pyroelectric detector. This allows the scene radiance to be referenced to the space background, which is about 3K. The radiometry data which is sent to the ground will have the space view signal subtracted from the scene view signal. To aid in determining the correct brightness temperature of a relatively cool target which was measured by a relatively warm instrument, the PPR contains ten internal thermistors on different optical elements.

For both photometry and polarimetry, the scene view flux passes through the filter and then through a Wollaston prism which gives two spatially separated anti orthogonally polarized beams. These beams are then detected by two silicon photodiode detectors. In addition, the polarimetry filters include a half wave retarder. Since one light beam is split by the Wollaston prism and directed to two detectors, a powerful means of determining a real signal from noise is its presence in both detectors.

3. PPR OPERATIONS DURING THE JUPITER TOUR

The PPR instrument has five modes of operation: Cycle mode (CYCLE), Radiometry mode (RAD), Photometry/Polarimetry mode (PP/PI), Photometry mode (PHOTOM), and Position Select mode (POS SEL). CYCLE mode will cycle through all the filters, RAD mode will cycle from the 17 μ m filter through the solar+ thermal filter and back, PP/PI mode will skip over the Radiometry filters, Photometry mode will cycle from the 618.7 nm filter through the 891.8 nm filter and back, and finally, POS SEL mode allows selection of any filter position. In the POS SEL mode, it is possible to command one, three, or five additional positions. In every I-node, it is possible to vary the number of samples taken while in a particular filter position before stepping to the next one.

As a result of the Galileo mission being performed with the low gain antenna, there are two additional highly constrained resources. The first is the number of telemetry bits received on the ground and the second is space on the tape recorder. During each orbit, the tape recorder will be filled only once during the spacecraft/Jupiter encounter period and subsequently played back during the cruise portion of the orbit.

To compensate for these constrained resources, changes are being made to the Galileo Command Data System (CDS) to enhance the PPR data return. The most significant change is the PPR Burst Mode capability, which enables PPR to return a much larger amount of data

than would otherwise have been possible. It allows pre-editing of the PPR data to delete redundant data and save only the unique data to a buffer in the CDS. This deletion of redundant data results in more observation time for the same number of telemetry bits to ground. Once the CDS buffer is filled, it "bursts" the data to the tape recorder at 7680 bits per second (the? lowest tape record speed). Since the nominal bit rate of the PPR is only 216 bits per second of the 7680, it is clear that this is a large savings in tape. Another important capability that is being added to the CDS is the ability to perform 10 ss1css compression on the PPR data. When the data are read from the tape recorder into the CDS in preparation for downlink, an algorithm known as Rice Compression (Rice, 1991) can be pm-formed on the data. It is estimated that this algorithm will give up to 1.3:1 compression of the PPR data.

4. PPR ICY SATELLITE OBSERVATIONAL PLAN

The PPR instrument will observe each of the four Galilean satellites, but here we will concentrate on the observations of the icy satellites: Europa, Ganymede, and Callisto. The Galileo two year Jupiter tour allows several 'targeted' encounters (<3,100 km distance): four Ganymede, three Callisto, and three Europa. In addition, it offers a few 'non-targeted' encounters (23,000" -80,000 km): one Ganymede, one Callisto, and two Europa. '1'able 2 shows the orbit number anti designation along with the targeted satellite, non-targeted satellite and Galileo's altitude at closest approach in each case. Although detailed planning of the observations has started, there will be time

allowed (starting six weeks prior to each orbit encounter) to accommodate small changes based on knowledge gained from returned data.

The PPR team has several general scientific objectives to be accomplished for each of the icy satellites. One objective is to investigate the thermophysical properties, especially the thermal inertia, of each of these bodies. This will be accomplished via observations called Dayside Global Thermal Maps (DGTm), Dayside Regional Thermal Maps (DRTm), and Darkside Thermal Maps (DRKMAP). The data from these observations will enable characterization of global variations in albedo and surface thermal inertia (which is affected by compaction and particle size) by comparing brightness temperatures to models. Inertia can be correlated to the surface geology and possibly used to determine relative surface ages.

Investigation of sub-resolution temperature variations will help characterize surface inhomogeneities. These sub-resolution temperature variations can be determined by comparing the temperature difference for different wavelengths using superposition of contributions from areas at different temperatures within the field of view. For Europa, these data will serve to locate any possible sources of endogenic heat. It is also important to evaluate the stability of surface volatiles which will be accomplished through the dayside temperatures in the DGTm and DRTm observations.

Voyager IRIS data showed a brightness temperature decrease of about 5K between 30 and 60 degrees phase (Spencer, 1987). 'I'bus, to determine the kinetic surface temperatures from the derived brightness temperatures, it will be necessary to put constraints on the anisotropy of the thermal emission. The PPR will gather data from a particular region at different phase angles to accomplish this objective. This observation set is known simply as Thermal Phase Observations ('I'0).

The tour also offers the opportunity to obtain very high (0.7 -7.7 km) resolution samples (HIRISS), which will enable the investigation of the thermophysical properties of the icy satellites at the highest possible spatial resolution. These samples will enable characterization of local variations in surface compaction. This data set will be an additional tool for studying the questions of surface age and composition, and volatile movement. In addition, it will provide a high resolution search for sources of endogenic heat on Europa.

The final general scientific objective is to investigate the surface optical properties, including the refractive index and particle size, for a variety of terrain types. This observation set is known as Polarimetry Phase Observations (I'0).

These observations are summarized in Table 3,

5., SATELLITE OBSERVATION DESIGN DETAIL.

In general, the PPR will scan approximately along a latitudinal band, and will "fly back," or slew very fast, to begin the next scan. In many cases, the design will have 50/50 coverage, ie. 50% overlap from field of view (FOV) to field of view and 50% overlap from scan to scan. The map will also cover the area of interest plus another half of a field of view or so to allow for scan platform pointing uncertainty. The following sections will give details on each of the observation types.

5.1 Darkside Thermal Maps (DRKMAP)

This observation will obtain as near to global nighttime coverage as the tour provides for each of the satellites. In general, we will position select to one radiometry filter with one additional position commanded. Typically, the filter choice would be $27\text{ }\mu\text{m}$ and $>45\text{ }\mu\text{m}$, and each filter would sample four times before stepping to the next. The time to take four samples with the $27\text{ }\mu\text{m}$ filter and four with the $>45\text{ }\mu\text{m}$ filter including the filter stepping time is 4.13 seconds. This 4.13 sec cycle time between plotted fields of view (Figure 1) is the way in which we design the 50% overlap from FOV to FOV. The resolution for these observations will be typically 220 km.

5.2 Dayside Global and Regions Thermal Maps (DGTm, DRTM)

On Europa, we will obtain as much coverage at all longitudes as the tour provides. For Ganymede and Callisto, we will obtain nearly

global c-coverage, but due to spacecraft resource limitations, we may not obtain all longitudes provided by the tour. Consequently, we would obtain 'regional' maps. These thermal maps will be done in at least one thermal filter, typically $27\text{ }\mu\text{m}$, with the possible addition of one other thermal filter if observing time and resources permit. '1'bus, the cycle time is either 0.5 sec for one sample in one filter or 4.13 sec for four samples in each of two filters plus stepping time. This observation will nominally be done at less than 30 degrees phase and a resolution of 220 km.

5.3 Thermal Phase Observations (TPO)

These observations are planned to be done once during the tour for Ganymede and Callisto and twice for Europa. Each TPO set will consist of three observations of the same longitude region at different phase angles. The phase angles are approximately 30, 60, and 90 degrees. A typical resolution will be 110 km for Europa and Callisto and 240 km for Ganymede. We will nominally position select to one radiometry filter, 27 μm , which has a cycle time of 0.5 seconds.

5.4 Polarimetry Phase Observations (PPO)

There will be two kinds of polarimetry phase observations: high resolution and low resolution. The high resolution observations will be very similar to the TPO observations (i.e. typically 110 km for Europa and Callisto and 240 km for Ganymede). They will be maps of the same longitude region at three widely spaced phase angles.

These will be done once for each icy satellite during the tour. The low resolution observations will consist of a single scan across the disk or a small mosaic. Typically, the target body will be slightly larger or slightly smaller than the PPR field of view. In other words, these observations may vary from disk integrated up to several PPR fields of view across. The observations will span 0-180 degrees phase with five degree resolution. These observations are not shown on Table 3. A set of these measurements will be obtained for each of the icy satellites providing complete phase curves of both photometric and polarimetric parameters. The PPR will be position selected to a polarimetry position with five additional positions commanded, (to get the complete polarization information). This choice has a cycle time of 4.10 seconds.

5.5 High Resolution Samples ($1111 < 1\{SS$)

High Resolution Samples (0.7 to 10 km) will be taken near the targeted satellite close approach. This observation can be a target of opportunity, i.e. it will follow the ground track as the spacecraft flies by the satellite. It can also be a small PPR dedicated map of a particular region of interest, or a ride-along map with another scan platform instrument, the Near Infrared Mapping Spectrometer (NIMS), in particular. A ride-along observation with the NIMS instrument will typically have a much slower scan rate than the PPR requires and will also give incomplete coverage, as the NIMS slit is S times the PPR diameter. The PPR will be position selected to one radiometry filter with a cycle time of 0.5 seconds.

6. SUMMARY

The PPR instrument will gather a wealth of more complete and higher resolution data for the Galilean icy satellites even with the reduced data return capabilities. The current observation strategy - global coverage at good resolution with reduced wavelength coverage - is thought to be a good compromise in light of these restrictions. The outline of the strategy presented here will give the scientific community the opportunity to comment. It is expected that the Galileo mission and the PPR instrument in particular will realize a very successful Jupiter tour.

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Table/Figure Captions

TABLE 1: PPR measurement functions and wavelengths. The PPR instrument has three distinct modes: polarimetry, photometry, and radiometry. Derived from Russell, et al, 1992.

TABLE 2: Galileo icy satellite encounters. The altitude refers to the spacecraft altitude at closest approach. There is no orbit five listed since it is during a solar conjunction period when the Sun - Earth - spacecraft angle is less than five degrees. This orbit is considered a 'phasing' orbit in the tour and no observations will be done.

TABLE 3: PPR planned icy satellite observations. The table breaks down the observations by type, icy satellite, and orbit. The approximate longitude covered for the Dayside Global and Regional Thermal Maps, the Darkside Thermal Maps, and the Thermal and Polarimetry Phase Observations is given for each orbit. The latitude/longitude of the closest approach point is given for the high Resolution Sample observations. The low resolution Polarimetry Phase Observations are not shown.

FIGURE 1: Example Darkside Thermal Map (DRKMAP) design. This is a preliminary version of the DRKMAP planned for the first Ganymede (G1) encounter. The resolution ranges from 95 km to 280 km. This design uses two thermal filters (27 μm and $>45 \mu\text{m}$; each sampled four times) with a corresponding cycle time of 4.13 seconds. A field of view is plotted every 4.13 seconds. The overlap is about

25% FOV-FOV and 25% scan to scan. This observation starts at approximately Ganymede closest approach -13.5 hours and has a duration of 2.5 hours.

Table 1. PPR Measurement Functions and Wavelengths

Measurement function	Center 1	Full width at half max
Radiometry	16.8 μm	4.2 μm
	21.0 μm	3.0 μm
	27.8 μm	7.2 μm
	35.5 μm	6.9 μm
	$\lambda > 45 \mu\text{m}$	45-110 μm
	Solar	0.3-4 μm
	Solar - thermal	0.3 -110-1 μm
Polarimetry	410.1 nm	60.0 nm
	678.5 nm	8.711111
	944.6 nm	10.8 nm
Photometry	618.7 nm	7.0 nm
	633.3 nm	8.611111
	648.0 nm	7.4 nm
	788.711111	11.911111
	829.3 nm	11.9 nm
	840.311131	7.1 nm
	891.8 nm	11.1 nm

Table 2. Galileo Icy Satellite Encounters

Orbit #	Designation	Encounter (Targetted = 'I') (Non-targetted = 'N')	Altitude (km)
0	J0	10 ('I')	1000
		Europa (NT)	32489
1	G1	Ganymede ('I')	500
2	G2	Ganymede ('I')	255
3	C3	Callisto ('I')	1100
		Europa (NT)	31947
4	E4	Europa ('I')	695
6	E6	Europa (T)	588
7	G7	Ganymede (T)	3065
		Europa (NT)	23244
8	G8	Ganymede ('I')	1584
		Callisto (NT)	33499
9	C9	Callisto (T)	416
		Ganymede (NT)	79961
10	C10	Callisto (T)	524
11	E11	Europa ('I')	1119

Table 3. PPR Planned Icy Satellite Observations

Orbit Identification									
J0 G1 G2 C3 E4 E6 G7 G8 C9 C10 E11									
Observations									
Dayside Global and Regional Thermal Maps									
Europa	S. Pole	220-340	240-330,170-195	160 Z10	130-240*,90-130	/ 70-250,90-120			
Ganymede	/ 40-240		300-20*,210-240,120-200*,35-60 60*,160,CS T 10						
Callisto	30-50,110-200		90-170,0-60		110-170,0-60 [10-] 65				
Dayside Thermal Maps									
Europa	130-180		80-170,330-350	0-110	20-100	250-280, 10-90			
Ganymede	320-70		/ 90-240		120-210,20-45	310-40*,210-240 210-240,0-30			
Callisto	290-30, 210-230		60-150 5 10v		310-0,1160-210 / 60-230,290-350 165-230,285-345				
Thermal Phase Observations									
Europa	240-270		120-150						
Ganymede						60-90			
Callisto	30-60								
Polarimetry Phase Observation									
Europa	240-270		120-150						
Ganymede						60-90			
Callisto						30-60			
High Resolution Samples									
Europa	0.4, 232.4		-0.3, 37.1		65.7, 144.1				
Ganymede	24.7, 110.5		84.6, 145.0		28.7, 273.9				
Callisto	13.3, 77.9		-42.3, 72.4		2.0, 259.2				
						4.8, 78.9			

Figure 1. Darkside Thermal Map Design for Ganymede 1 lincounter

